EM375 MECHANICAL ENGINEERING EXPERIMENTATION

INCLINING EXPERIMENT
"BOATS LAB"

PURPOSE: The aim of this laboratory is to determine the vertical location of the center of gravity, $\overline{KG}$, of a ship model in the normal load condition. In addition, the student will gain experience with regression and uncertainty analysis.

DESCRIPTION OF THE APPARATUS: The figure below shows an overhead (plan) view of the Floating Ship Model Stability Demonstrator Device 27-B-1. The model has four 0.15 lbs weights installed on the aft center post (number 2 in the figure).

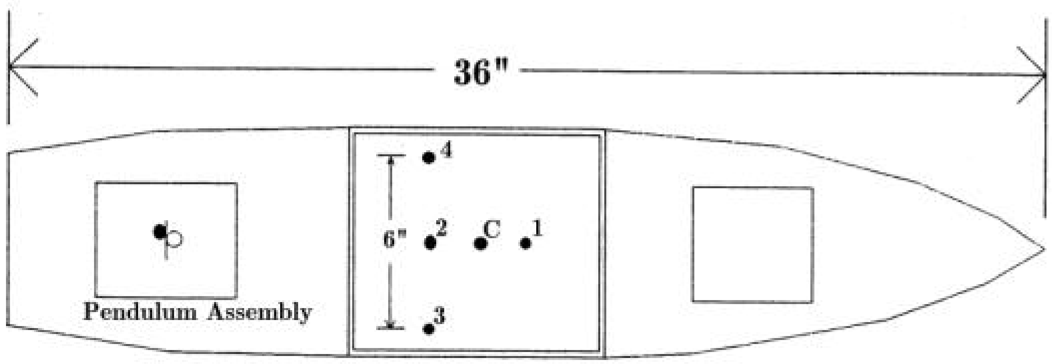

Figure 1: Top view sketch showing the inclining weight positions.

THEORY: The inclining experiment is performed to accurately obtain the vertical height of the center of gravity of a ship above the keel, $\overline{KG}$. The results, fully tabulated and calculated, are set down in the "Inclining Experiment Booklet" for each class of ship. Following subsequent alterations and weight changes, new values of $\overline{KG}$ are calculated based on this data.

The expressions used in the inclining experiment are derived using the following drawing:

M Location of the metacenter obtained from curves of form
G Location of the center of gravity (weight force down)
B Location of center of buoyancy (buoyant force up)

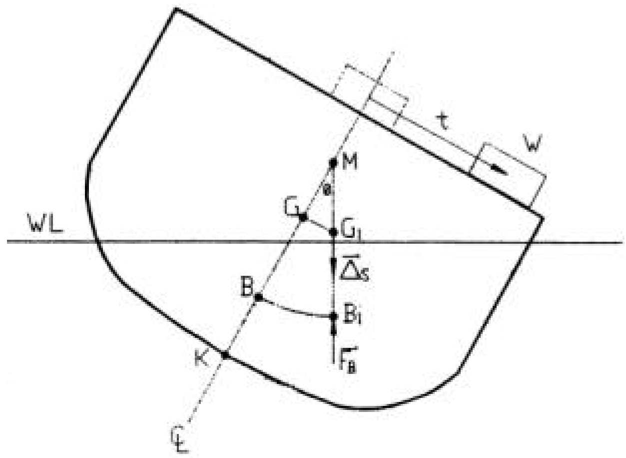

Figure 2: Cross section of the model showing the locations of K, B, G and M

The horizontal shift in the ship's center of gravity, $\overline{GG_1}$, is calculated by the weight shift theorem:

$$\overline{GG_1} = \frac{(w)(t)}{\Delta}$$

where D is the weight of the ship, w is the weight that is moved, and t is the distance it is moved.The product *(w)(t)* is sometimes called the inclining moment. Note that *M* is the metacenter, whose location is obtained from the ship's curves of form. From relations shown by the triangle GG_1M:

$$\overline{GG_1} = \overline{GM}.\tan(f)$$

Substitution and simple arithmetic yields:

$$\overline{GM} = \frac{(w)(t)}{\Delta\tan(f)} = \frac{\text{inclining moment}}{\Delta\tan(f)}$$

In the experiment the tan of the angle of inclination, tan(f) is measured directly using a pendulum. The metacentric height, $\overline{GM}$, is calculated using equation (3) as follows. Usually several inclinations are made to both port and starboard, using different weights, with intermediate checks at zero inclination. Using the data, the tangents of the angles of inclination from the initial position and the moments of the inclining weights from their initial positions are linearly regressed. The plot of moment *(w)(t)* vs. *tan(f)* should be a straight line if the ship's displacement (weight), D, is constant. Any variation from a straight line indicates that the conditions for conducting the experiment were not satisfactory, or errors have been made. The slope of the straight line fitted to the data can be used to solve for $\overline{GM}$ as follows:

$$slope = \frac{(w)(t)}{\tan(f)}$$

therefore,

$$\overline{GM} = \frac{(w)(t)}{\Delta \tan(f)} = \frac{slope}{\Delta}$$

$\overline{KG}$ (with four weights and pendulum onboard) is calculated using the equation below after obtaining $\overline{KM}$ from the tables of form:

$$\overline{KG_1} = \overline{KM} - \overline{GM}$$

This value of $\overline{KG}$ must be corrected for any changes required to return the ship to a normal load condition (i.e., remove the weights and pendulum).

$$\overline{KG_1} = \frac{\left(\overline{KG_0} \times \Delta_0\right) + \sum\left(w_i \times \overline{Kg_i}\right)}{\Delta_1}$$

where $\overline{KG_1}$ and Δ_1 are obtained in the inclining experiment. Rearranging:

$$\overline{KG_0} = \frac{\left(\overline{KG_1} \times \Delta_1\right) - \sum\left(w_i \times \overline{Kg_i}\right)}{\Delta_0}$$

$$\overline{KG_0} = \frac{\left(\overline{KG_1} \times \Delta_1\right) - \sum\left(w_i \times \overline{Kg_i}\right)}{\Delta_1 - \sum w_i}$$

Where:

$\overline{KG_0} = \overline{KG}$ corrected for removal of the inclining apparatus

$\overline{KG_1} = \overline{KG}$ with the inclining apparatus

Δ_0 = Displacement corrected for removal of inclining apparatus

Δ_1 = Displacement with inclining apparatus = $\Delta_0 + \sum w_i$

w_i =- Weights of individual inclining components (4 weights & 1 pendulum)

$\overline{Kg_i}$ =Heights of centers of gravity of inclining components

PROCEDURE: (Record the hull number of your specific model)

1. Verify that the model is in the normal load condition as follows:

   a. Check that the solid-flooded tank is full and securely installed with the flooded side down in the center compartment. Make sure there is no loose water in the model.

   b. Check that the four 0.15 lbs inclining weights are on the aft-center post (2 in figure 1).

2. Determine the approximate center of gravity of the pendulum assembly by balancing it on a ruler. Determine the height of the center of gravity of the pendulum assembly above the keel, KG. Determine the height of the center of gravity of the inclining weights above the keel.

3. Measure the length of the pendulum from pivot to the transverse scale.

4. Weigh the model including the weights and pendulum. Weigh the pendulum and weights individually. Determine the location of the metacenter (KM) from the Tabular Curves of Form.

5. Measure the distance from the center post to the outboard weight posts.

6. When floating the model in the tank, **do not** place the end pins in the grooves in the ends of the tank, otherwise the model will not heel properly. Throughout the lab, wipe any excess water off the deck. Water will cause errors in your results.

7. With all four weights on the center post, adjust the balance weight to eliminate any initial list.

8. For various numbers of weights on the outboard post (1 to 4) record the pendulum deflection. Whatever weights are not used on the outboard post should remain on the center post. Repeat this process for both outboard posts, i.e., port and starboard. Randomize the order in which you conduct the various trials.

9. After data have been recorded for the two outboard posts, verify that the boat has maintained the zero-list from step 7. If it has changed, notify your instructor. You should end up with a total of 10 trials.

10. Graph the data, remembering that the signs (+/-) of the inclining moment and tilt angle depend on whether the weights are on the port or starboard post. Determine the slope and y-intercept values using linear regression analysis, and the standard error of the slope.

11. Determine $\overline{GM}$. Determine the uncertainty in $\overline{GM}$ using the standard error of the slope and your estimate of the uncertainty in Δ .

12. Correct $\overline{KG_1}$ to obtain $\overline{KG_0}$.

<u>**REPORT:**</u> Prepare an **individual** formal report that determines the KG with an estimate of the 95% confidence limits. Note that the uncertainty in KG is dependent on the slope obtained from the linear fit to the data.The error of the slope is given by:

$$S_{a1} = S_{yx}\sqrt{\frac{N}{N\sum_{i=1}^{N} x_i^2 - \left(\sum_{i=1}^{N} x_i\right)^2}}$$

The report should include a Title Page, Abstract, Nomenclature, Introduction, Results, Discussion, and Conclusions. Appendices should include Sample Calculation and Observed Data. Theory and Procedure can be omitted.